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Demonstration and verification of post combustion capture using solvent scrubbing

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Abstract

This paper will present Doosan Power Systems' Post Combustion Capture (PCC) development, testing and verification activities. Preliminary results from the Boundary Dam TKO™ process, RS™ solvent trial and the results from the ERTF test facility will be discussed.
Doosan Power Systems is developing competitive PCC technologies to capture carbon dioxide (CO_2) from coal and natural gas fired power plants for commercialization by 2020. Doosan Power Systems has licensed solvent scrubbing technology from HTC Purenergy Inc., which is based in Regina, Saskatchewan, Canada. HTC have developed an optimised Post Combustion Capture (PCC) process known as the Thermal Kinetics Optimization™ (TKO) process which is designed to substantially reduce the energy requirements of the PCC process for the capture of CO_2 from coal and natural gas fired power plants.

Doosan Power Systems is currently undertaking FEED studies and preparing commercial bids for full-scale solvent scrubbing plants, comprising all equipment from flue gas desulphurisation (FGD) plant outlet to CO_2 compression plant inlet. Among these are the CCPILOT100+ and Basin Electric PCC demonstration projects.

The TKO process is currently under a formal technology verification programme at the upgraded Boundary Dam demonstration pilot plant capturing approximately 4tonnes/day of CO_2. Long term performance of HTC's proprietary RS™ solvent is currently being assessed for CO_2 removal effectiveness and the long term performance of the solvent. Solvents are also tested for degradation, heat stable salt formation and propensity for corrosion within the various system components.

Doosan Power Systems has installed a PCC solvent scrubbing pilot plant on the 160 kW_t Emissions Reduction Test Facility (ERTF), located at its R&D centre in Renfrew, Scotland, to capture approximately 1tonne/day of CO_2 and to permit further development and optimization of the process. The ERTF is capable of firing a wide range of world traded coals and produces flue gases representative of full scale plant. The ERTF solvent scrubbing plant will be used to carry out performance testing on a range of solvents, packings and suitability of a range of materials.

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The testing and verification programmes at both Boundary Dam and the ERTF will be used to substantiate the scalability of HTC's technology under real-world operating conditions. Of paramount importance during the verification programmes are the actual rate of solvent degradation under industrial conditions, solvent make-up requirements, steam consumption and other auxiliary power requirements which add to power plant parasitic losses, such as that for fans to overcome the pressure drop created by column internals and associated pipework.

Keywords: CCS; Demonstration; Post Combustion; CO_2

1. Introduction

Carbon dioxide (CO_2) is one of the greenhouse gases whose increasing concentration within the atmosphere is believed to have direct impact on global climate change. The combustion of fossil fuels for the generation of electricity is a major contributor to the concentration of CO_2 in the atmosphere. Fossil fuel currently supplies over 85% of the world's energy needs, due to it being a reliable technology for energy production, low cost, availability and energy density [1]. The Energy Information Administration (EIA) within the U.S. Department of Energy (DOE) estimates that the consumption of fossil fuels will increase by 27% over the next 20 years. A major international effort is therefore required to ensure cost effective energy generation to sustain global economic growth while reducing CO_2 emissions. The European Commission recommended the targets to cut EU greenhouse gas emissions by 20% from the 1990 level by 2020 with the ambition to go to a 30% cut if other non-EU states were prepared to collaborate. The UN climate summit reached an outline of a global agreement in Copenhagen in December 2009, the so-called Copenhagen accord "recognises" the scientific case for keeping temperature rises to no more than 2°C. Technologies that control CO_2 emissions from fossil fuel combustion sources will play a key role in meeting this major challenge.

The worldwide drive to reduce CO_2 emissions combined with the continued key role of fossil plant in meeting energy requirements means that carbon capture and storage (CCS) will be required. Legislation will require new plant to be carbon capture ready and, beyond a certain date, to be equipped with CCS. It is also likely that existing plant will require CCS to be retrofitted once the technologies have been demonstrated to be viable at full scale. Emission trading and CO_2 caps will also provide a strong incentive to install CCS on both existing and new plant.

Post Combustion CO_2 Capture is one of the most commercially ready technologies for carbon abatement of fossil fuel power plants because of its parallels with natural gas sweetening. However, the energy requirement for solvent regeneration is the main technical drawback of this technology, mainly due to the use of low pressure steam as a heat source, which reduces the turbine output of the steam turbine. Solvent chemical degradation by flue gas impurities such as O_2, SO_x, NO_x and particulates, as well as solvent thermal degradation by the regeneration process increase the solvent makeup cost and decrease the plant reliability. Corrosion can have a direct impact on the plant economics since it results in unplanned downtime, production losses and reduced equipment life. In order to commercialize PCC technology application to full scale power plants, highly reliable, low capital and operating cost PCC plants need to be developed.

2. Background

Doosan Power Systems – HTC Purenergy Alliance

In 2008, Doosan Power Systems executed a global license agreement with HTC Purenergy, to offer their process technology in commercial-scale, post combustion projects worldwide, in addition to this agreement; Doosan Power Systems also acquired a 15% share in the company. In order to capitalize on the expertise, industry links and experience within the two companies, an extensive technology transfer took place, with around 30 engineers and specialists from Doosan Power Systems and Doosan Heavy Industries & Construction seconded to HTC Purenergy.

HTC Purenergy is headquartered in Regina, Saskatchewan, at Innovation Place, one of Canada's newest university integrated research parks. Situated next to the International Test Center for CO_2 Capture at the University of Regina, HTC is strategically positioned amongst leading-edge petroleum and environmental sciences facilities, including the new International Performance Assessment Centre for CO_2 Geological Storage (IPAC-CO2). HTC participates in collaborative research with the University of Regina which has pioneered Carbon Capture and Storage technology development since 1992. The University now boasts one of the most comprehensive carbon capture research and development facilities in the world; the University's Greenhouse Gas Technology Centre is home to the International Test Center for CO_2 Capture (ITC). The ITC is dedicated to fundamental and bench-scale research with in-house facilities that include a fully-operational CO_2 capture pilot plant. The pilot plant is used to test and evaluate the performance of the latest CO_2 absorbing solvents, column internals, and the latest in heat integration process designs that minimise energy usage in the CO_2 capture process.

Doosan Power Systems PCC Technologies

Doosan Power Systems engineering protocols are designed to provide a fully integrated solution to maximize the efficiency of flue gas CO_2 capture from coal and natural gas fired power plants. Doosan Power Systems is developing competitive PCC technologies to capture carbon dioxide (CO_2) from coal and natural gas fired power plants for commercialization before 2020. Doosan Power Systems has licensed solvent scrubbing technology from HTC Purenergy Inc. HTC have developed the Thermal Kinetics Optimization™ (TKO) process [2]. The TKO^{TM} process presents a suite of robust and scalable process systems which are brought together to load and unload CO_2 solvent flows with reduced energy penalties and operational overhead. It is designed to substantially reduce the energy requirements of post combustion capture of CO_2 from coal and natural gas fired power plants through improved heat recovery, thermal balancing and optimized process flow.

The amine based Regina Solvents (RS™) are proprietary designer solvents that can be formulated to provide cost effective optimized separation of CO_2 from any flue gas stream. The solvents are formulated with unique ingredients having specific properties that contribute to the desired characteristics of the solvent to suit a specific task. The solvents can be customized depending on the content of the flue gas to ensure increased absorption and loading characteristics, improved stripping and stability while reducing corrosion. The main potential advantage of the system is that when used with RS™ solvents, power plant steam consumption can be reduced.

Doosan Power Systems modeling/design/simulation processes for CO_2 capture systems, has the ability to scale and model, absorption columns and packing profiles and solvent absorption ensures maximum efficiencies are achieved while reducing the energy penalties in solvent regeneration. The customized process control/ instrumentation and data acquisition systems for all components of the CO_2 capture process ensure the continuous optimization of the overall working capacity for the capture process achieving the most cost effective solution in single and multiple site operations.

3. Boundary Dam Demonstration Plant

Boundary Dam Power Station is a coal fired station owned by SaskPower, located near Estevan, Saskatchewan, Canada. The station consists of six units with a combined generating capacity of 813MW$_{e.}$ The Boundary Dam solvent scrubbing demonstration plant was first built in 1987 (SO_x baghouse, various upgraded instrumentation, new control system, data acquisition equipments were added afterwards), and became a dedicated carbon capture test facility in 2000. Since then, extensive long-term operating experience has been obtained for a range of solvents, process and packing configurations. The solvent scrubbing plant operates on a slipstream of flue gas 0.5 MMSCFD (15 vol% CO_2, 5 vol% O_2, 15 vol% H_2O, 380 ppmv SO_2 and 350 ppmv NO_x) resulting in approximately 4 metric tonnes of CO_2 captured per day.

The TKO^{TM} process is currently undergoing a formal technology verification program at the upgraded Boundary Dam demonstration pilot plant. Long term performance of HTC's proprietary RS™ solvent is currently being assessed for CO_2 removal effectiveness. Solvents are also tested for degradation, heat stable salt formation and propensity for corrosion within the various system components. Recent test runs, on lignite-derived flue gas have shown high absorption efficiency (around 85% CO_2 captured), low solvent degradation rate and low steam consumption – of the order of 1.1 kg of steam consumed for each kg of CO_2 captured). This testing utilizes proprietary RS™ solvent and the TKO™ process configuration with more than 1400 hours of testing to date. HTC, through the course of 2010, will complete the validation of this process through stringent technology verification with progressively larger scales of operation at the Boundary Dam demonstration site and another U.S. reference plant.


Figure 1 Boundary Dam Solvent Scrubbing Demonstration Plant

4. Emissions Reduction Test Facility

Doosan Power Systems has installed a PCC solvent scrubbing pilot plant on the 160 kW_t Emissions Reduction Test Facility (ERTF), located at its R&D center in Renfrew, Scotland, to capture approximately 1 metric tonne of CO_2 per day and to permit further development and optimization of the capture process. The ERTF is capable of firing a wide range of world traded coals and produces flue gases representative of full scale plant. The solvent scrubbing pilot plant has been designed in house and is used to carry out performance testing on a range of solvents, process configurations, packings and customer coals. The testing and verification programs at both Boundary Dam and the ERTF will be used to further validate the scalability of HTC's technology under real world operating conditions. Of paramount importance during the verification programmes are the actual rate of solvent degradation under industrial conditions, solvent make up requirements, steam consumption and other auxiliary power requirements.

Description

The 160kW_t Emissions Reduction Test Facility was originally built in 1980's to investigate in-furnace NO_x reduction technologies. The facility has since been extensively upgraded to allow investigation of Selective Catalytic Reduction (SCR) and Selective Non-Catalytic Reduction (SNCR), both of which are post-combustion NO_x reduction processes, and in 2008 was upgraded for the oxyfuel combustion process. A schematic diagram of the ERTF and the main equipment associated with it is shown in Figure 2.

The ERTF furnace is 5.0 m long and 0.5 m in diameter, arranged vertically. The burner, a residence-time scaled-down version of a commercial low- NO_x axial swirl burner, is located at the top of the furnace and fires vertically downwards. The facility can operate on either natural gas or coal or can fire at higher rates by using a combination of both fuels. Following fly ash removal by the ESP the flue gas is exhausted to atmosphere via an induced draught fan [3].

Control of the ERTF is broadly manual but data logging is automated, by means of a data logging system using proprietary software. Analysis of the data (averaging and consistency checking) is carried out "just off line" during the set-up period for the following test. Spurious data are quickly identified allowing repeat tests to be undertaken as appropriate. Continuous gas analysis for O_2, CO and NO_x is undertaken at the furnace exit. Gas analysis is performed utilizing 6 continuous emissions analyzers. These units are protected by moisture capture systems; all measurements are thus presented on a dry basis. Under typical operation the concentrations of NO_x, O_2, CO, SO_2 and CO_2 are analyzed at the furnace exit; NO_x and O_2 concentrations are analyzed at the SCR outlet or ESP outlet. The test facility was significantly upgraded in 2008 for oxyfuel operation as part of the first phase of the collaborative OxyCoal-UK program.

Impurities in the flue gas, particularly SO_x and NO_x will lead to the degradation of the solvent and production of heat stable salts [4]. In order to minimize solvent degradation, the flue gas impurities must be reduced to a very low level upstream of the PCC absorber. Therefore Doosan Power Systems has installed a Flue Gas Desulphurization (FGD) unit downstream of the ESP to control the SO_2 content and the temperature of the gas entering the absorber column.

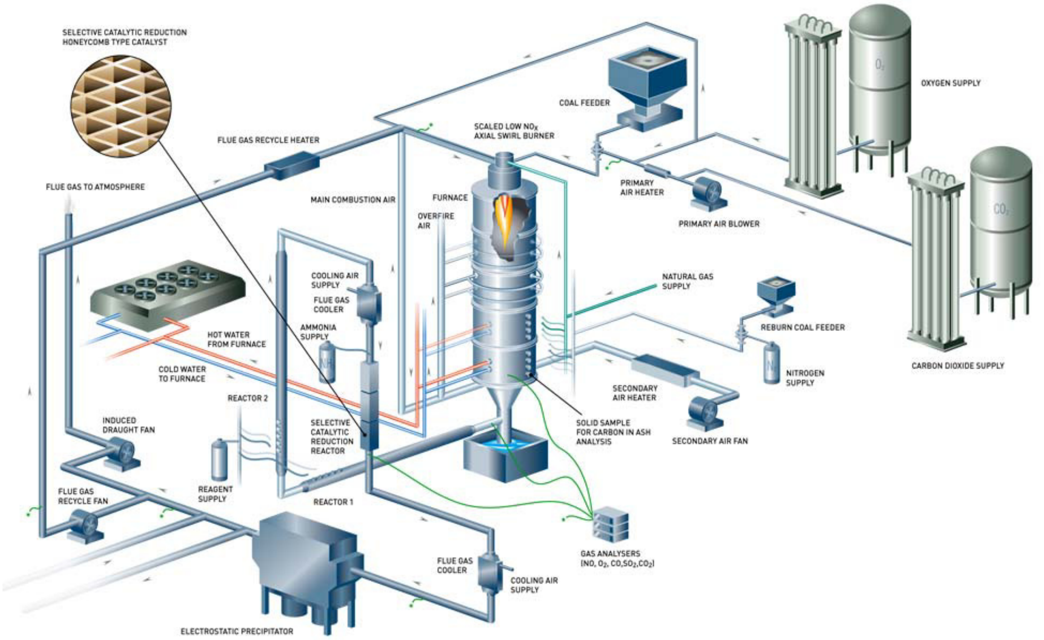

Figure 2 Emissions Reduction Test Facility

Solvent Scrubbing

The solvent scrubbing system is shown in Figure 3. The flue gas from the FGD exit flows counter-currently with the solvent through the absorber column. The absorber column contains commercially available structured packing and is fitted with a series of ports suitable for temperature and pressure measurement and liquid and gas-phase sampling along its height. The column features a number of solvent inlet locations to offer a range of operating configurations. The scrubbed flue gas, or off gas, exits the absorber column before entering the water wash column. The water wash also contains structured packing and counter-current contact between the off gas and circulating water removes any entrained solvent. The off gas then leaves the water wash column and is recombined with the CO_2 product stream before being emitted to atmosphere.

The remaining equipment items shown in Figure 3 include the solvent handling, heat recovery and solvent regeneration operations. The rich solvent (loaded with CO_2) exiting the bottom of the absorber column, is pumped through a lean-rich exchanger (in one configuration of the system) where the temperature is increased due to heat transfer from the lean solvent (partly loaded with CO_2) exiting the stripper column, before being introduced into the stripper column. The stripper column, also containing structured packing, is fitted with a series of temperature and pressure measurement points along its height. The heat required to liberate the absorbed CO_2 from the solvent in the stripper is supplied by steam from a 100kW electric steam generator. Stainless steel gasketed plate-and-frame heat exchangers are used throughout the upgraded plant for heat transfer operations since they offer a small-footprint, low temperature approach as well as their potential for expansion/modification and ease of disassembly/maintenance.

One of the key design features of the facility is the ability to demonstrate the TKO™ process developed by HTC Purenergy, to substantially reduce the energy requirements for capture of CO_2 from flue gas. The TKO™ system maximizes the internal re-use of energy within the regeneration unit operations, reducing the requirement for the application of external heat. Pumping duties in the solvent and water circuits are met by a range of variable-speed drive diaphragm pumps which offer the ability to deliver comparatively low flow rates at variable delivery pressures. The post combustion capture system is designed to minimize environmental impact: all liquid waste generated by the process is retained for disposal by waste management specialists; and process equipment is located within bunds for spill containment. As part of the safety procedures adapted to ensure the safety of test facility personnel, permanent CO_2 detection alarms have been sited around the test facility structure, in addition to personal CO_2 detection alarms worn by personnel whilst on site.

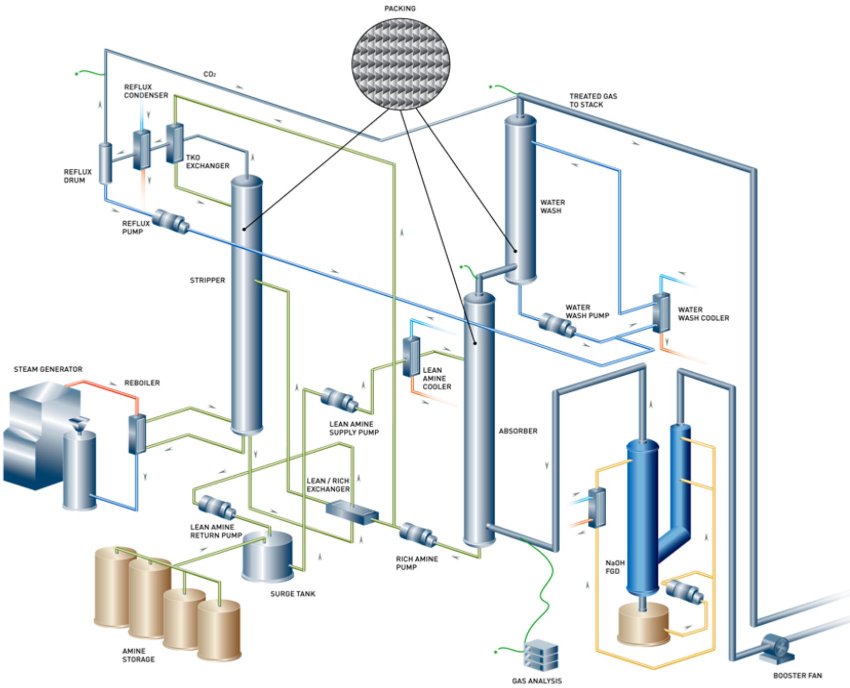

Figure 3 ERTF PCC Solvent Scrubbing Upgrade

ERTF Test Programme and Results

Test programmes will be undertaken on the ERTF to gain operational experience and obtain performance data, in particular, CO_2 capture rate and solvent regeneration energy for selected solvents over a wide range of process conditions. The initial test phase focused on developing “baseline” results for the test facility. Aqueous monoethanolamine (MEA) 30% w/w was used as the solvent to allow meaningful comparison with publicly available data from existing solvent scrubbing pilot installations.

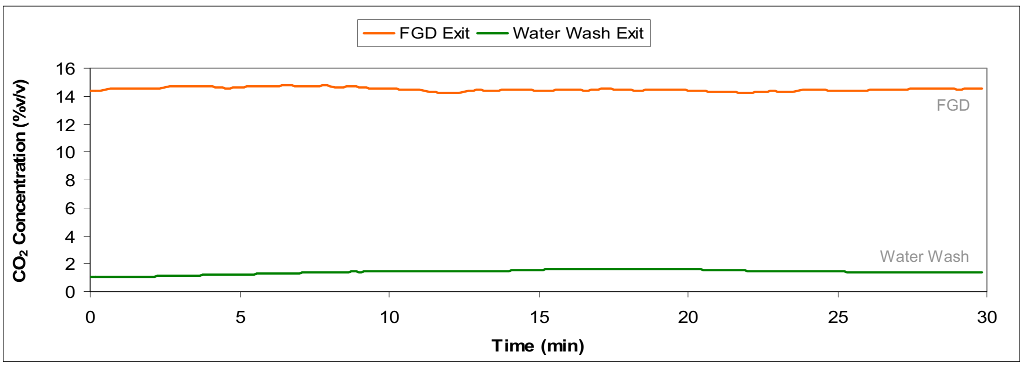

Figure 4 Gas Analysis for CO_2 at FGD Exit (Absorber Inlet) and Water Wash Exit.

Figure 4 shows the CO_2 concentrations in the flue gas at FGD outlet and the off gas at the outlet of the water wash. The CO_2 concentration at FGD exit is 14.49 %v/v and at the water wash outlet 1.40 %v/v resulting in a capture rate of ~91% which meets the design requirement [5].

Testing of the ERTF solvent scrubbing process is ongoing at the time of writing. Testing will seek to establish the operational impacts of such process variables as: absorber inlet flue gas temperature; absorber inlet solvent temperature; lean solvent loading; solvent circulation rate; stripper bottom pressure; reboiler steam pressure and others upon the performance of the system. Later testing may include further process parameter changes as well as changes to the process configuration – including testing of alternative structured and random packing materials and testing of alternative solvents such as the HTC Purenergy RS2™ formulated solvent or other proprietary solvents. Further, the test facility will be used to carry out targeted testing, e.g. capture of CO_2 from flue gas derived from coals specific to a power station fuel diet for commercial contracts.

The extensive testing activities that have been completed by HTC Purenergy with support from the University of Regina at the Boundary Dam facility and International Test Center, combined with validations studies performed on commercial carbon capture plants, will be used to validate the process technology under real world operating conditions. Key parameters that will be validated during these programs include: the actual rate of solvent degradation under industrial conditions; solvent make-up requirements; steam consumption and other auxiliary power requirements.

5. CCPILOT100+ Demonstration Plant

This project will see Doosan Power Systems CO_2 capture technology installed at Ferrybridge power station in Yorkshire, United Kingdom. Ferrybridge is a 2,000MW$_e$ coal-fired station owned and operated by Scottish and Southern Energy plc (SSE). The £20 million project focuses upon the construction and demonstration of Europe's largest post-combustion CO_2 capture plant – a 5MW$_e$ slipstream equivalent to 100 metric tonnes per day of CO_2 captured. Vattenfall of Sweden are partnering with Doosan Power Systems to develop this world class facility along with three UK universities, all leaders in the training of researchers in this sector. The project is co-funded by the Technology Strategy Board, the Department for Energy and Climate Change (DECC) and the Northern Way partnership [5][6].

Following a one year construction and commissioning phase, a two year research and test program will then take place, from early in 2011, demonstrating Doosan Power Systems CO_2 capture technologies. In addition to the industrial research and development focus, university researchers will participate in the project to gain operational experience, carry out complementary research and help to build the UK's skills capacity in this sector.

Figure 5 Ferrybridge power station

6. Basin Electric Demonstration Plant

Doosan Power Systems was selected to undertake a major carbon capture project Front End Engineering Design (FEED) study with US utility Basin Electric Power Cooperative. The study is led by Doosan Power Systems in partnership with HTC Purenergy.

Basin Electric Power Cooperative's CO_2 Capture Demonstration Project is located at its Antelope Valley Station (AVS), located near Beulah, North Dakota, US. AVS is a lignite-based facility situated on the mine-mouth with two 450MW$_e$, sub-critical boilers.

The FEED for AVS has been based upon the application of the Doosan/HTC PCC process technology. The PCC facility will comprise of: flue gas pre-treatment; CO_2 absorption; solvent regeneration; and CO_2 compression and dehydration. The CO_2 Capture Plant will have a total nominal capacity of 3,000 tons per day, separating CO_2 from a 120MW$_e$ slipstream from Unit No. 1. The captured CO_2 would be compressed, dehydrated, and fed into an existing carbon dioxide pipeline system.

The eventual aim of the project is to use the captured CO_2 for enhanced oil recovery or sequester in a geological formation close to the power plant. The FEED commenced in February 2010 and is on schedule to be completed before the end of 2010. When completed, the FEED will provide Basin Electric with a comprehensive assessment which, along with a number of other key project factors they are evaluating, are necessary to decide whether to proceed with the Engineering, Procurement and Construction (EPC) phase of the carbon capture project.

7. Conclusion

Doosan Power Systems and HTC Purenergy have aligned to develop and supply commercial scale PCC technology for utility power plant.

The upgrade of Doosan Power Systems ERTF for Solvent Scrubbing is a significant step in the development of our PCC technology offering and will further enhance Doosan Power Systems experience in designing solvent scrubbing technology. The ERTF simulates the entire process of modern coal-fired power generation. It can burn real coals and natural gas, and includes a range of gas clean-up systems, before CO_2 capture takes place.

Two significant PCC projects are currently being undertaken by Doosan Power Systems – a 5MW$_e$ slipstream plant at SSE Ferrybridge (CCPilot100+) and a 120MW$_e$ FEED project for Basin Electric at Antelope Valley. Further, the commissioning and testing programs undertaken at the ERTF, Ferrybridge and the Boundary Dam plants will provide invaluable knowledge which will be incorporated for the full commercial deployment of PCC technology for power plant.

The ongoing research and development and cumulative experience of pilot plant operation will ensure that the deployment of commercial scale PCC plant can be achieved with rigorous operating guarantees, robust procedures and competitive performance, delivering an effective means to reduce greenhouse gas emissions from power generation.

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